DESIGN & CONSTRUCTION OF AN AUTOMATIC ABSORPTION DYNAMOMETER FOR A MASTER CAR BUILDER'S DROP TEST MACHINE

MILTON C. SHEDD

ARMOUR INSTITUTE OF TECHNOLOGY

1909

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The Design and Construction of an Automatic Absorption Dynamometer for a Standard Master Car Builder's Drop Test Machine

A THESIS

PRESENTED BY

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MECHANICAL ENGINEERING

1909

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THE OBJECT

The object of this thesis is the design and construction of an absorption dynamometer which will automatically give a record of the force of a blow transmitted to it by the fall of the hammer of the fifty-foot Standard Master Car Builder's Drop Test Machine owned by Armour Institute of Technology.

INTRODUCTION

THE DROP TEST MACHINE

The drop test machine of Armour Institute of Technology is located on the east side of Dearborn Street, between Thirty-Third and Thirty-Fourth Streets. Views of the machine are shown by the photographs, pages 7 and 8. The top of the standards or masts is fifty-four feet above the foundation springs, allowing for a sheer drop of about forty-five feet. The hammer as ordinarily used weighs 1660 pounds, but additional weights may be added to make it 2000 pounds in all. This will give a maximum force of 900000 foot-pounds of energy available for testing purposes. The hammer is picked up by a magnetic clutch which is automatically released by a striker set at any desired height. Power for elevating the hammer is obtained from a ten horse-power motor-driven hoist conveniently housed at the side of the machine in a fireproof steel and sheetiron shed.

The base of the drop test is a very heavy solid block of cast iron, mounted on coil springs which take up the shock of the blow in a travel of about two inches. If desired, this base may be blocked up so that there is a solid impact transmitted direct to the six-foot concrete foundation. Heavy bolts through this foundation

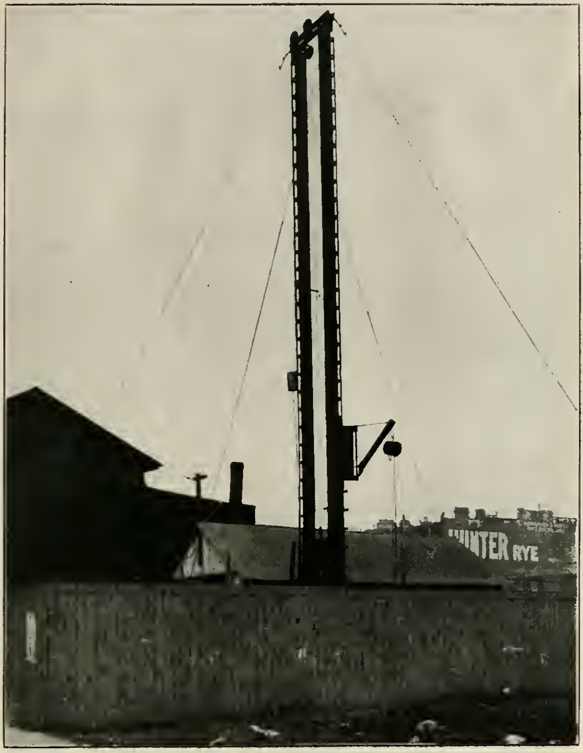

FIG. 1.

GENERAL VIEW OF DROP TEST MACHINE

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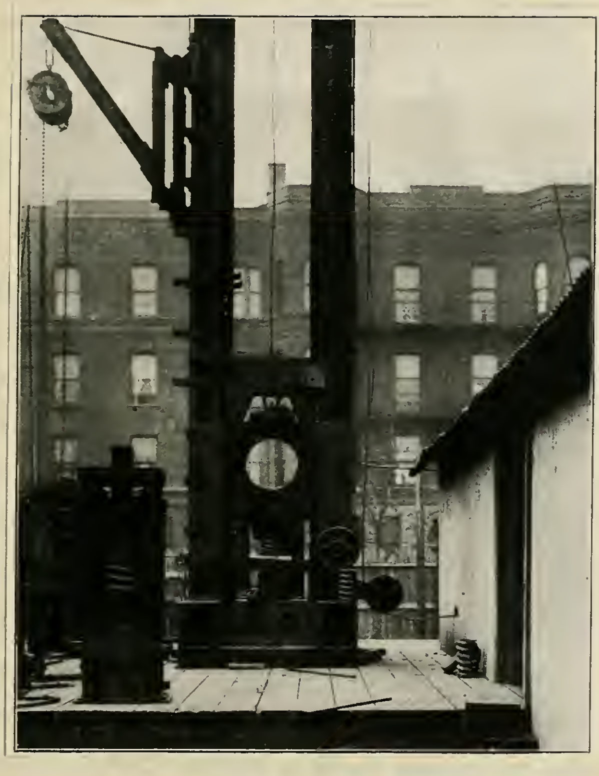

FIG. 2.

REAR VIEW OF DROP TEST MACHINE

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hold the masts rigidly to it, but for additional rigidity, guy ropes are fastened from the top of the masts to anchors imbedded in the ground. A four-ton differential block and chain mounted on a movable arm from the side of the mast permits of the easy placing of apparatus to be tested. Any size or shape of apparatus may be held in place by a complete equipment of frames and riggings.

THE TESTING OF DRAFT GEARS

While the impact maghine may be used for a variety of tests on car wheels, axles, brake gearing, or other apparatus which in actual use is subjected to sudden shocks or collisions, this machine has been used especially for testing draft gears, which are placed behind the couplers on all heavy steam and electric cars to absorb the shock of two cars coming together. The average yearly repair cost of such cars is said to be about $75 and over fifty percent of the repairs are made to the couplers, draft gears and sills of the cars. Consequently there has lately arisen a great amount of didcussion as to the relative efficiencies of the various makes of draft gears. The underlying principle of most of the gears is the action of various friction devices, aided to a large extent by spiral or eliptical springs. Were it not for the effect of the rebound, a draft gear

could be made simply of a large spring which would absorb the blow. The perfect gear is one which will absorb the entire shock of a collision without transmitting any of it to the underframe of the car, and of course, every gear is perfect for a very light blow, the efficiency decreasing as the blow becomes greater. The utility of the the impact machine in this kind of testing may be illustrated by the fact that a drop of fifteen feet with the 2000-pound hammer produces the same effect on a gear as the collision of an 80000-pound car running at a speed of 15 miles per hour. A drop of twenty feet or more will usually injure the gear or its frame. The travel of a gear, ~~gear~~, from two to four inches, is the compression of its springs. This is usually taken for each drop , because when it is a maximum, the gear is "solid", and the blow is transmitted direct to the underframing of the car.

The amount in foot-pounds of a blow given to a gear by the hammer is the product of the height of the drop by the weight of the hammer, the amount of friction between the hammer and its guide rails being negligible. The use of a dynamometer,then,is to find the blow which is transmitted by the draft gear to its frame.

THE DESIGN OF THE ABSORPTION DYNAMOMETER

The complete assembly and detail drawings of the dynamometer are shown in PLATES I, II, and III, but for convenience, reference may be made to the cut, Fig.3, page 12, which gives a cross-sectional view. The essential principle of this dynamometer is the transfer of the energy from a solid to a liquid, where the force of the blow may be measured. The main difficulty encountered is that of enclosing the liquid so that its pressure could increase with the energy given to the solid body, without allowing the escape of any of the liquid. Schemes for measuring the the pressure by a system of levers, as is done in the ordinary testing machine, can not be used, because of the probable effect of the sudden blow upon any such arrangement. The diameter of the dynamometer was limited to 27 inches by the width of the space between the masts. Allowing roughly for a diameter of 20 inches for the receiving plunger, it was found that a drop of 25 feet would give a pressure of about 2000 pounds per square inch in the liquid under this plunger. This pressure is too great to be easily measured by ordinary indicators, and so the plan of using a reducing plunger was decided upon.

With a diameter of the receiving plunger of 19 inches

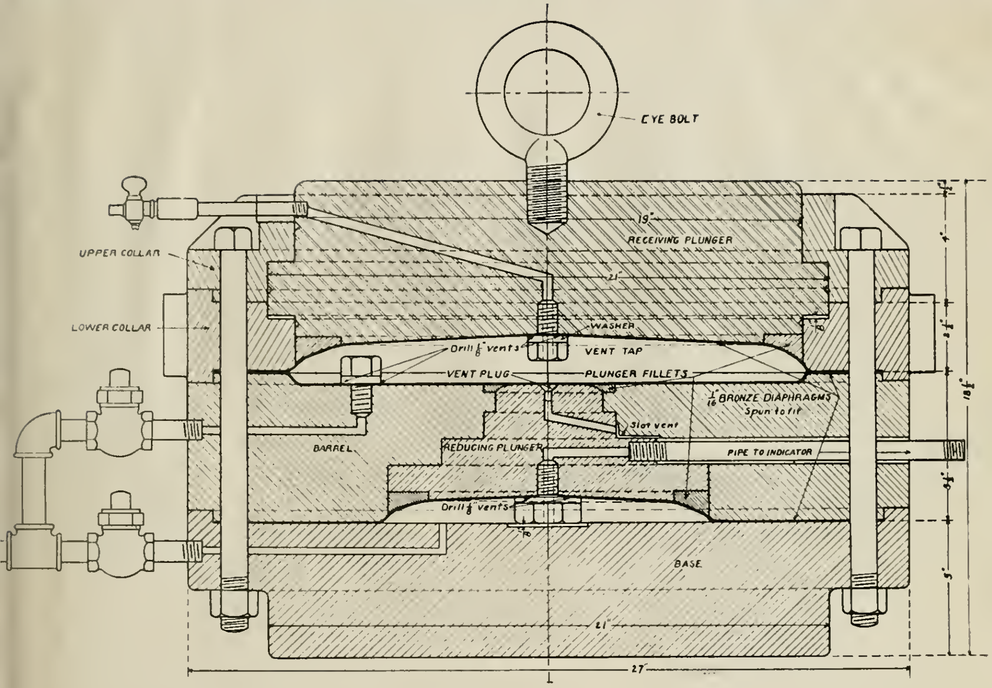

FIG. 3.

CROSS-SECTION VIEW OF DYNAMOMETER

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BILL OF MATERIAL
for
ABSORPTION DYNAMOMETER

Article	NO.	Material
Receiving Plunger	1	Steel
Reducing Plunger	1	Bronze
Upper Collar	1	Cast Iron
Lower Collar	1	Cast Iron
Barrel	1	Cast Iron
Base	1	Cast Iron
Diaphragms	3	Bronze
Eye Bolt	1	Steel
Eye Bolt Plug	1	Steel
Vent Taps and Washers	3	Steel
Vent Plug	1	Steel
Plunger Fillets	3	Brass
Bolts	30	Steel
Check Valves (½")	2	Brass
Stop Cock (¼")	1	Brass

and diameters of the two surfaces of the reducing plunger of 4 and 12 inches, respectively, then a pressure of 1 pound per square inch on the liquid in the lower cavity indicates a total pressure of

$$\frac{19^2 \times 12^2}{4 \times 4} = 3250 \text{ pounds}$$

on the receiving plunger. If no liquid leaks past the check valves, and if the liquid is incompressible, the plungers should have no travel whatever for any blow; but as these conditions can not be accurately counted on, each plunger is given an eighth of an inch maximum travel. Each plunger has V-shaped grease rings about its circumference to give lubrication for a free vertical motion. Although the weight of the receiving plunger is about 500 pounds, the plunger may be floated by a water pressure of 2 pounds, corresponding to a head of 4.6 feet.

The water in the upper cavity is entirely surrounded by the two diaphragms, while that in the lower is enclosed by the diaphragms and the base. The provisions made made to prevent shearing of the diaphragms when the plungers descend are perhaps the most important features of the design. Attached to the lower side of each plunger is a ring of soft brass (plunger fillet), whose lower side ends in a very sharp edge. When the plunger descends,

this edge will wedge in between the diaphragm and the inner side of the collar surrounding the plunger, without shearing the diaphragm. These diaphragms are of brass, a comparatively soft but tough metal which will contract and expand to the slight extent necessary without injury. The one over the top of the reducing plunger is protected by a ring of brass with a similar thin edge, which will bend over as the diaphragm is forced down, and prevent the diaphragm from coming into contact with any sharp edges which might tend to shear it.

A hole through the reducing plunger to the "slot vent" connecting with the large drilled hole through the barrel, permits of the escape of air or liquid which might collect under the diaphragm, and also furnishes a ready means of detection in case there should be leakage inside the dynamometer. The opening at the top of the reducing plunger is protected by the vent plug shown in the details? A hole through the receiving plunger provides for the escape of air from the upper cavity, and a similar hole through the reducing plunger connecting with the "pipe to indicator" provides a means of obtaining the pressure in the cavity under the plunger. The liquid is admitted to the cavities from a tank overhead through the check valves on the left.

Water is the liquid which is used in the dynamometer during warm weather as it is practically incompressible and most convenient to handle. In cold weather, however, the water would freeze and burst the dynamometer. The following mixture has a low freezing point, is cheap, and seems to give good results:- 1 part glycerine, 3 parts wood alcohol, and 6 parts water.

An eye-bolt in the top of the receiving plunger provides a ready means of placing the dynamometer, and lugs on the lower collar hold it in place between the masts. When it is in place, the eye-bolt is to be replaced by the eye-bolt plug, whose top will be flush with the surface of the plunger. The "vent taps" serve to prevent any of the liquid from getting between the diaphragm and the metal surface in the several places where openings have to be made through the diaphragms.

In all calculations made for the strength of the castings and forgings, the factor of safety was 6. The shoulder of the receiving plunger was made of such strength that a drop of 25 feet can safely be made, even if there is no liquid under the plunger. The collars and barrel were made to resist a pressure of 2000 pounds per square inch. The thickness of the receiving plunger is such that a drop of the ton weight through 25 feet on any portion would not shear it. The vertical bolts holding

the dynamometer together were calculated for a maximum tension equal to the force of the blow of a ton weight falling through 25 feet, although it is probable that they will never be subjected to such a strain. Throughout the entire design it was endeavored to combine the greatest strength with the smallest possible weight, and to make the dynamometer as compact as could safely be done.

THE DESIGN OF THE AUTOMATIC SWITCH

The lower reservoir is connected to the indicating device by means of flexible brass piping. This device has been made from an ordinary steam engine indicator by the addition of a small geared motor to provide continuous high speed rotation of the drum. Instead of the usual indicator cards, paper cards prepared with certain chemicals which leave a black mark when written on with a brass stylus are used. (An effort was made by the writer to make these cards in the chemical laboratory, as they are rather expensive to purchase, but the attempt was not altogether successful, the writing being indistinct. It would probably take quite a lot of experimenting to discover the chemicals used.) Thus a sharp brass point may be used instead of the usual pencil, producing clear-cut, accurate cards. This point is pressed against the paper by means of a small solenoid, which is made to act by the closing and breaking of electrical connections.

To make this solenoid automatically take a card at the proper time, an adjustable, automatic switch , PLATES IV and V, was designed. Briefly, it depends on the rise and fall of a weight, which makes and breaks the electric circuit. The design of the switch was restricted by

BILL OF MATERIAL
for
AUTOMATIC SWITCH

Article	No.	Material
Frame	1	Cast Iron
Adjustable Stop (Complete)	1	Cast Iron
Trip Lever (Complete)	1	Aluminum
Movable Weight	1	Aluminum
Wire Rope Tip	1	Steel
Turn Bolt	1	Steel
Lock Wheel	1	Cast Iron
Grooved Pulleys	2	Cast Iron
Tap Bolts	2	Steel
Stud Bolt	1	Steel
Switch Contacts	2	Brass
Striker (COMplete)	1	Steel
Wire Cable (½")	20 Ft.	Steel

the small space in which it could be installed on the side of the drop test machine. A striker on the descending hammer, designed for uniformly accelerated motion, strikes a hardened steel roller at one end of the lever arm, which act causes connection to be made between the two insulated contact knives. At the same instant, the weight on the lever arm is thrown up along the wire cable to strike against the adjustable stop and fall back on the lever, thus disconnecting the contact knives. The length of time that the point is against the drum can therefore be nicely adjusted by changing the height of the stop above the frame. The whole apparatus is mounted on the heavy wire cable so that it may be raised or lowered according to the height of the gear to be tested.

This wire cable is fastened to the top of the frame, passes over a grooved pulley, down through the outer part of the frame and through the movable weight to a lower grooved pulley, and thence to the wire tip on the turnbolt, which, by screwing into the frame, tightens the cable. The cable is so hung along the mast that no part of the apparatus is within 3/8 of an inch of the falling hammer. The lever arm and weight are of aluminum to make the inertia effect as small as possible; if made of heavier metal, the acceleration of the falling hammer

would probably shear off the lever before its inertia of rest could be overcome.

The knife contacts are insulated by an eighth inch air gap and by mica rings. One contact wedges into the other, requiring a smart blow from the movable weight to dislodge it. The lower grooved pulley may be clamped tight by the lock-wheel, so that the cable is prevented from moving. The design of the parts presented no difficulties, once the general idea was worked out, the main problem being to design all details so that they would require the minimum amount of machine work.

CONSTRUCTION OF THE APPARATUS

The billet of drop-forged steel for the receiving plunger and the three diaphragms were secured from firms in Chicago; all castings were made and all the machine work was done at the shops of Armour Institute of Technology. The progress of construction was carefully watched in all the shops to make certain the accuracy of the work as handled by the shop assistants and students. The drawings were given to the pattern-makers on January 11, 1909, and by May 1, 1909, both the dynamometer and the switch were completed and in place.

No essential changes from the design as originally made made were found necessary. It was out of the question to secure the diaphragms of bronze, so they were spun out of "spinning brass" to fit templates accurately made after the machine work was completed. A careful endeavor was made to secure the best possible castings and to have good workmanship throughout.

When the dynamometer was put together, it was thought best to screw the two large"plunger fillets" on their respective plungers. A packing of ordinary wire solder was put between the diaphragms, two rings being placed just inside the bolt holes between the two upper diaphragms, and two rings between the lower diaphragm

and the "base". All the nuts were then tightened up by a long wrench and the dynamometer, weighing about 2600 pounds, was carted over to the impact machine. Several light drops were made on it, after which the nuts were tightened again. The necessary piping to connect it with the supply tank overhead was secured from stock, but a special union had to be made to connect with the flexible pipe to the indicator. Practically all the machine work on the automatic switch was done by the writer. The principal difficulty encountered was in drilling and tapping the mast fot the bolts for the grooved pulleys.

The apparatus complete is shown by the photograph on page 24.

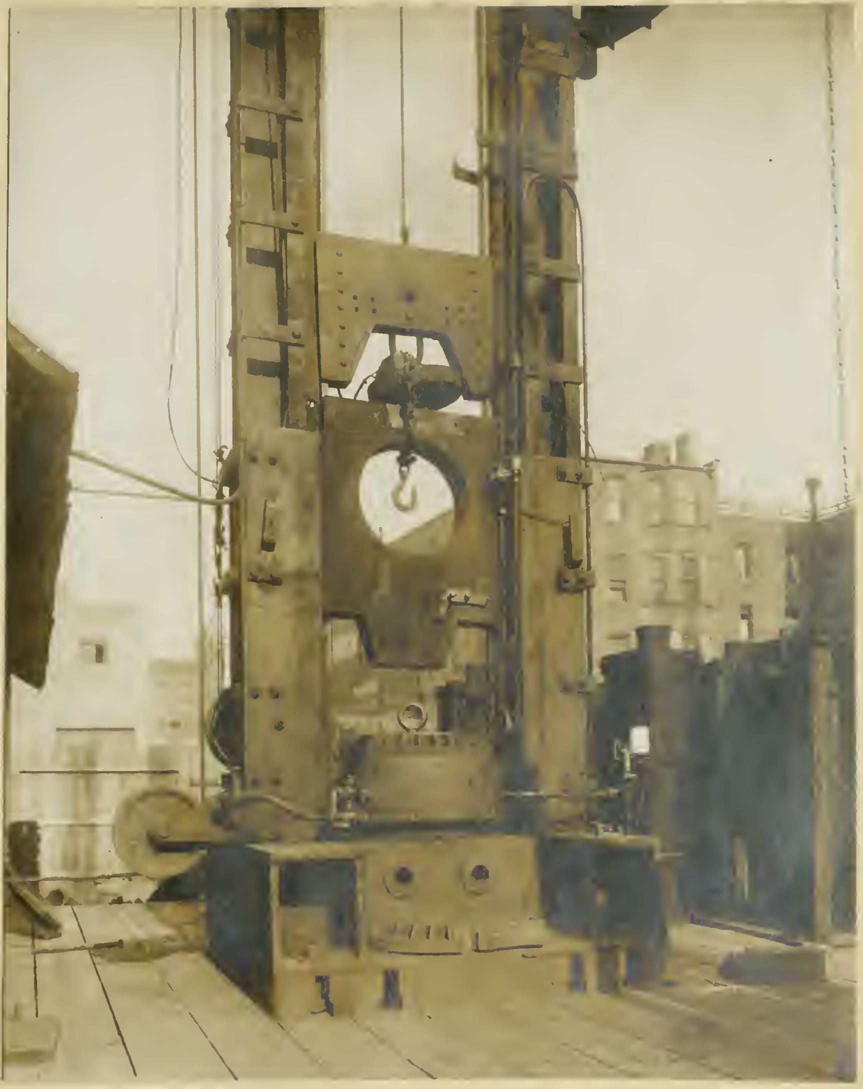

FIG. 4.

PHOTOGRAPH OF APPARATUS IN POSITION

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THEORY OF THE DYNAMOMETER IN DETAIL

Figures 5and 6,page 26, show cards which were obtained from the dynamometer, Figure 5 being a card from a five-foot drop on the dynamometer alone, and Figure 6 a card from the test of a gear from the same height of drop. The necessary data for the calculations are given with each card. The ratio of the movement of the small piston in the indicator to the movement of the pencil point is 18 to 100. Therefore, for a height of card of 1 inch, the travel of this piston is 0.18 inches. The work done on this indicator piston is the product of the mean pressure per square inch exerted against it by its area in square inches ($=\frac{1}{2}$ sq. in.), multiplied by the travel of the piston in feet, whence the work on the indicator piston becomes

$$54.6 \times \frac{1}{2} \times \frac{.18}{12} = .41 \text{ foot-pounds.}$$

Now, since 1 pound pressure in the indicator piston equals 3250 pounds pressure on the top of the dynamometer, the total energy absorbed by the dynamometer is

$$.41 \times 3250 = 1332.5 \text{ foot-pounds.}$$

The energy of the falling hammer, weight 1660 pounds, is

$$5 \times 1660 = 8300 \text{ foot-pounds.}$$

The efficiency of the dynamometer, then, is

$$\frac{8300 -- 1332.5}{8300} = 83.9\% :$$

that is, 83.9 per cent of the energy imparted to the dyna-

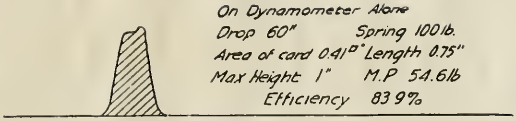

FIG. 5.

INDICATOR CARD - DROP ON DYNAMOMETER ALONE

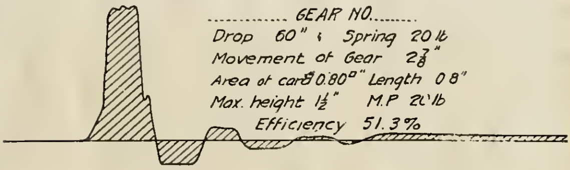

FIG. 6.

INDICATOR CARD - DROP ON DRAFT GEAR

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mometer is transmitted to the anvil or base of the impact machine, the remaining 16.1% being absorbed by the dynamometer. In a like manner, the combined efficiency of the gear and dynamometer is found to be 92.16 %.

Let the efficiency of the gear alone be represented by X. Then 1--X is the per cent, and (1--X)8300 is the energy in foot-pounds transmitted to the dynamometer from the gear. Also (1 -- .839) X (1--X) X 8300 is the energy transmitted to the foundation by the dynamometer. From the second card, Figure 6, this energy is (1-.9216) x 8300. Hence,

$$(1--.839) \times (1--X)8300 = (1--.9216)\ 8300,$$

whence

$$X = \frac{(.161--.0784)}{.161} = 51.3 \text{ per cent.}$$

This simply means that 51.3 % of the energy imparted to the gear by the falling weight is absorbed in the gear. All gears may be compared on this basis. As shown by the movement of this gear, which had a total compressibility of 4 inches, the force of the blow compressed it

$$\frac{2\ 7/8}{4} = 72\ \%$$

of its maximum compression.

The card shows how the pressure vibrates above and below the ordinary pressure line - that due to the pressure of the water in the dynamometer when at rest - and finally assumes a new pressure line. This latter is due

to the increased weight on the receiving plunger after the blow before the magnet picks up the hammer; while the former is caused by the recoil of the springs under the anvil.

So far as could be learned, no work has ever been done in testing any kind of railway appliances in an impact machine equipped with a dynamometer - although an extensive correspondence was carried on with various railroad officials. The theory as above described was worked out with the assistance of Mr. A. H. Anderson of the Institute.

CONCLUSION

It was intended that a calibration curve for the dynamometer should have been worked out, by plotting the efficiencies for various drops, but unfortunately, before any real testing could be done, the upper and lower collars both cracked at a drop of 5 feet, and experiments had to be abondoned. The apparatus was taken apart, and an examination of the fractures showed blow-holes at two of the four breaks. The metal seemed to be in layers, one of a distinctly darker color, proving that the castings contained poor metal. There was no direct blow on the two collars, as the receiving plunger was floating at the time. Examination of the plunger showed that it had not bulged, so that the failure was caused simply by the jar on the poor castings and was not due to any error of design.

The diaphragms were not damaged in the least by the broken collars, and showed no signs of use, in spite of twenty-odd drops which had been taken. This seems to indicate the correctness of their design. The lower packing was in place and entirely watertight; but the pressure of the water on the top packing had forced it out to the bolt holes and had caused several slight leaks. It would probably be better to use some form of packing which would offer more resistance to being displaced by the

pressure of the water acting against it. To be on the safest side as regards the strength of the collars, they should be made of cast steel rather than of cast iron, as the number of bolt holes in a comparatively small area tends to weaken the metal.

In regard to the automatic switch, it was found that for low drops the striker designed for uniformly accelerated motion simply pushed the whole apparatus to one side, although for drops of more than about six feet it seemed to work well. A striker with blunt edge caused the switch to act for low drops, but gave too violent a blow for high drops. It seems ,then,that two strikers will have to be used if a large range of drops is made during a test. Although but a few indicator cards were taken before the castings cracked, the switch showed that it fulfilled its purpose; for by adjusting the stop to give a length of card of about five inches, and by raising the frame some fifteen inches above the top of the dynamometer, several excellent cards were taken.

Candidly, however, there is no real need of the automatic switch. The tracing point may be placed against the paper when the small motor is started, and left there while the drum revolves until the motor is stopped after

the drop. The point would of course become dull after a number of cards had been taken, but the brass points are very cheap and may be easily replaced. Since the motor has been overhauled and geared directly to the drum, the friction of the pencil on the paper does not tend to vary the speed of rotation of the drum to any extent. The point would simply trace a fine line on the paper, and would interfere in no way with the accuracy or distinctness of the card. Doing away with the switch would do away with the bother of adjusting it for various heights and with the bother of changing the strikers during the drop.

Summing up the conclusions obtained from the small amount of testing done, both the dynamometer and switch appear to be adapted for the purposes for which they were designed, although the switch does not seem necessary for the convenient taking of cards.

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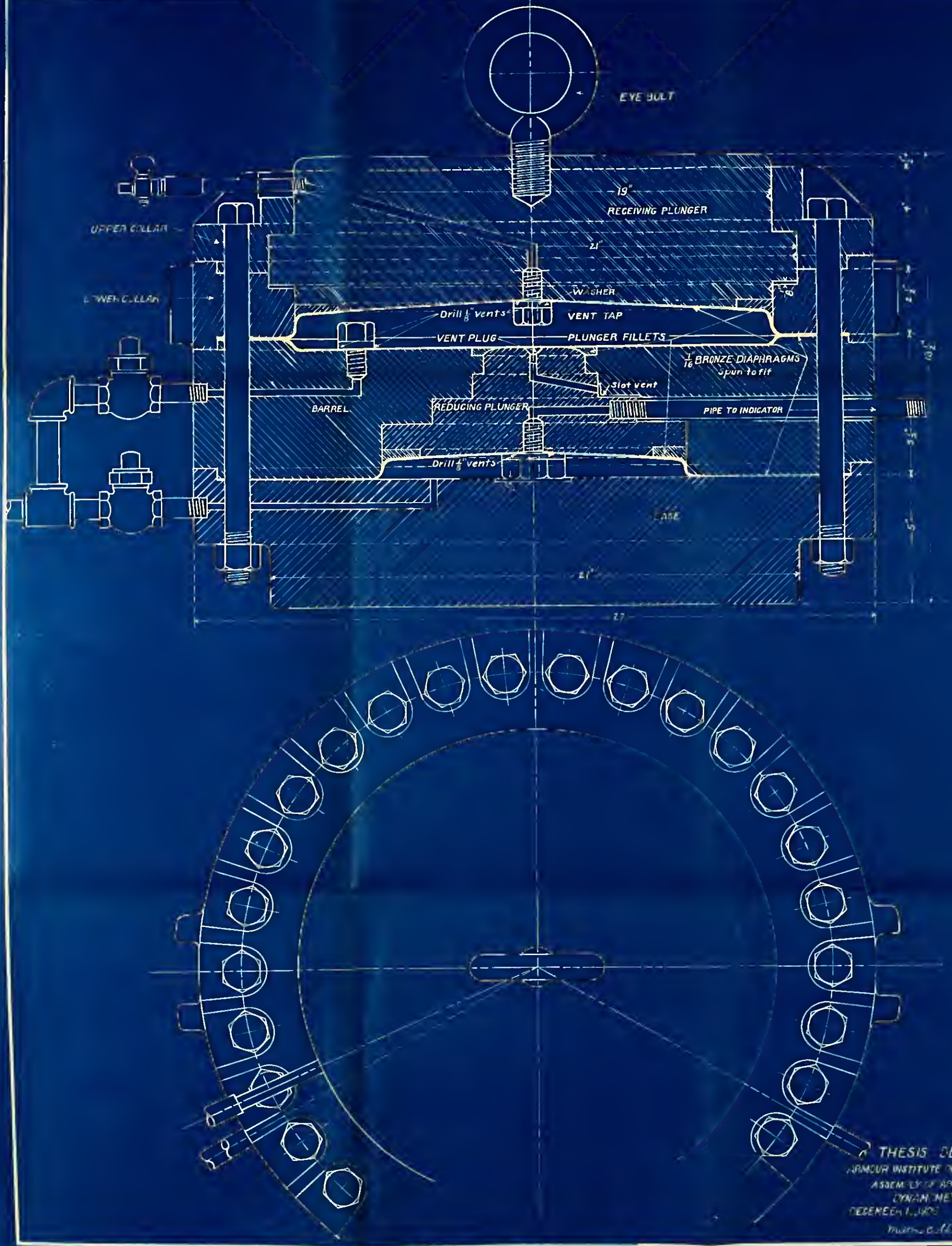
PLATE I

ASSEMBLY OF DYNAMOMETER



THESIS DESIGN
ARMOUR INSTITUTE OF TECHNOLO
ASSEMBLY OF ABSORPTION
DYNAMOMETER
DECEMBER 1, 190[illegible]
SCALE

[illegible]
[illegible]
[illegible]

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PLATE II

DETAILS OF DYNAMOMETER

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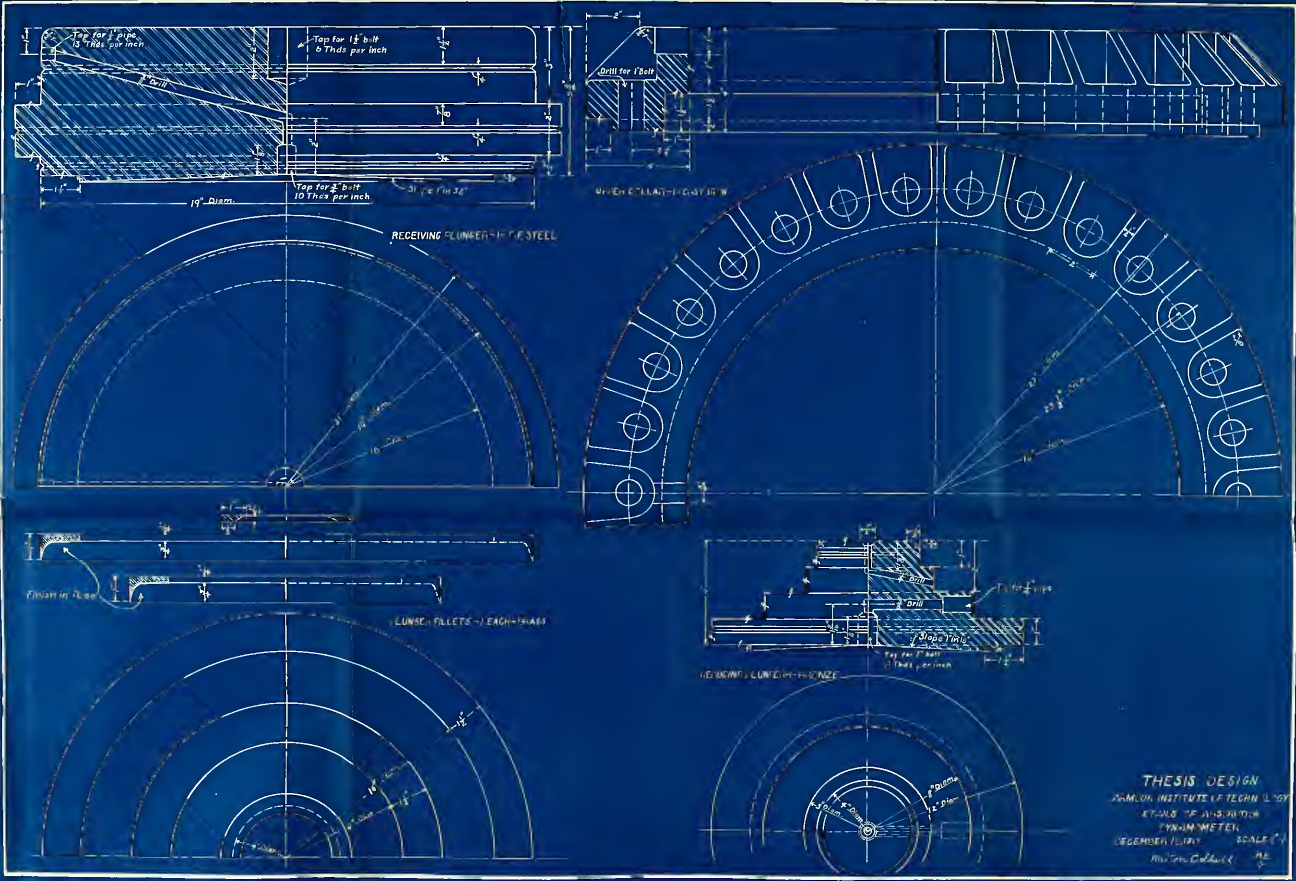
Tap for ½" pipe 13 Thds per inch
Tap for 1½" bolt 6 Thds per inch
Drill
Tap for ¾" bolt 10 Thds per inch
Slope 1 in 32"
19" Diam.
RECEIVING PLUNGER—1—C.F. STEEL
Drill for 1" Bolt
UPPER COLLAR—1—CAST IRON
Diam.
Finish in Place
PLUNGER FILLETS—1 EACH—BRASS
Drill
Tap for ½" pipe
Slope 1 in 16
Tap for 1" bolt 8 Thds per inch
RECEIVING PLUNGER—BRONZE
5" Diam.
4" Diam.
8" Diam.
12" Diam.

THESIS DESIGN
ARMOUR INSTITUTE OF TECHNOLOGY
DETAILS OF ABSORPTION
DYNAMOMETER
DECEMBER [illegible] SCALE [illegible]
Milton Caldwell M.E.

[illegible]
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PLATE III

DETAILS OF DYNAMOMETER

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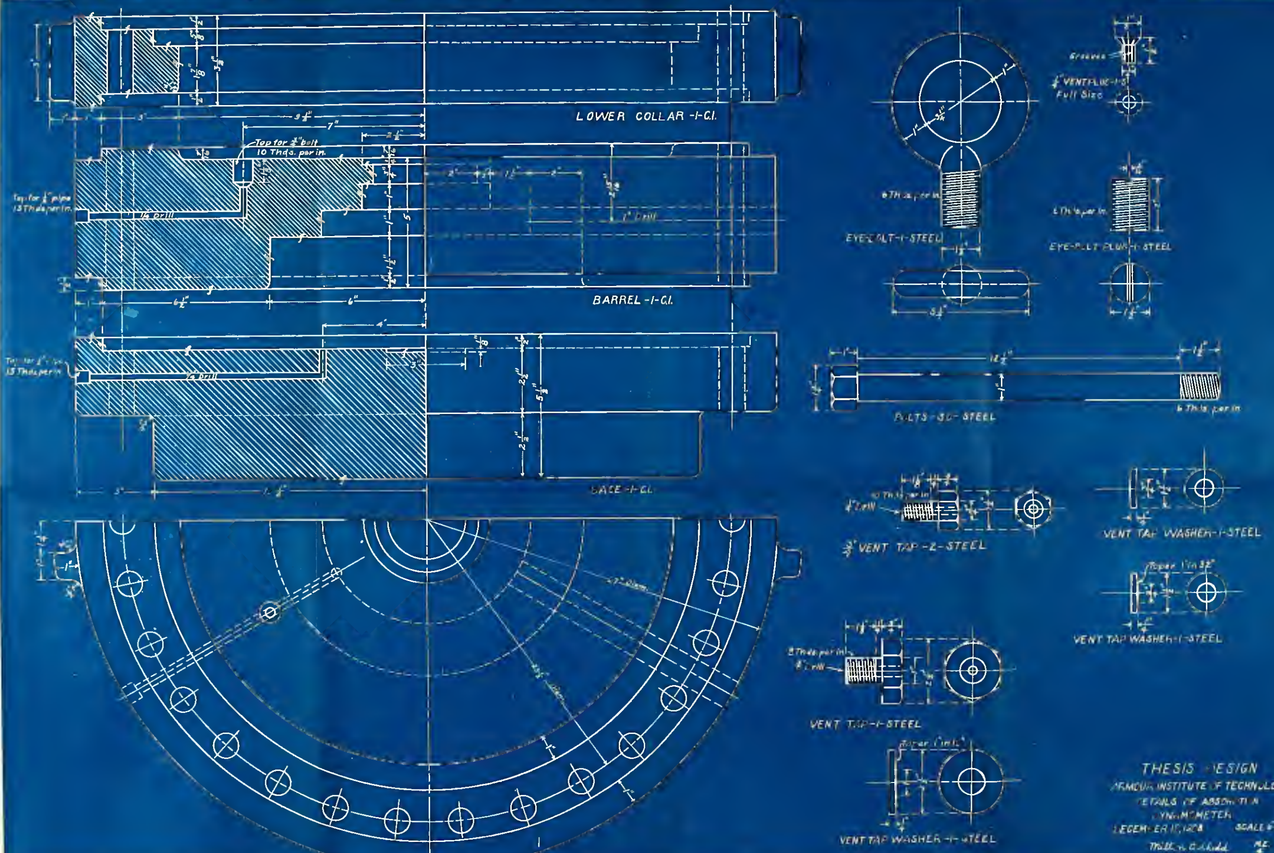
LOWER COLLAR - 1 - C.I.
BARREL - 1 - C.I.
BASE - 1 - C.I.
Tap for ¾" bolt 10 Thds. per in.
Tap for ⅛" pipe 15 Thds. per in.
1" Drill
EYE-BOLT - 1 - STEEL
6 Thds. per in.
EYE-BOLT PLUG - 1 - STEEL
¼" VENT PLUG - 1 - S. Full Size
Grooves
BOLTS - 30 - STEEL
6 Thds. per in.
⅜" VENT TAP - 2 - STEEL
VENT TAP - 1 - STEEL
VENT TAP WASHER - 1 - STEEL
VENT TAP WASHER - 1 - STEEL
VENT TAP WASHER - 1 - STEEL
Taper 1" in 32"

THESIS DESIGN
ARMOUR INSTITUTE OF TECHNOLOGY
DETAILS OF ABSORPTION
DYNAMOMETER
DECEMBER 1?, 1908 SCALE 6"=1'
[illegible] M.E.
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PLATE IV

ASSEMBLY OF AUTOMATIC SWITCH

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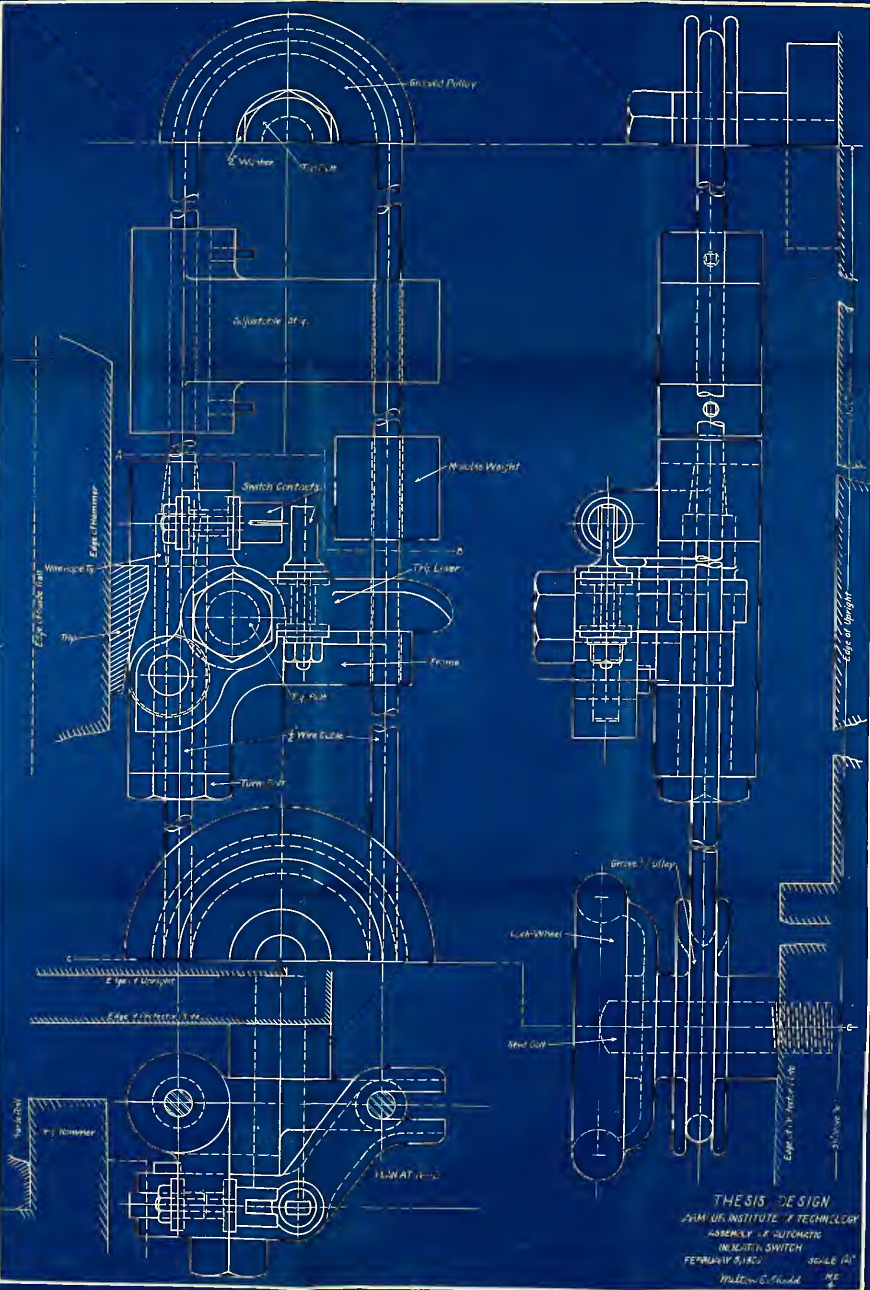

THESIS DESIGN
ARMOUR INSTITUTE OF TECHNOLOGY
ASSEMBLY OF AUTOMATIC
INDICATOR SWITCH
FEBRUARY 5, 1909 SCALE 1/4"
Milton E. [illegible] M.E.

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PLATE V

DETAILS OF AUTOMATIC SWITCH

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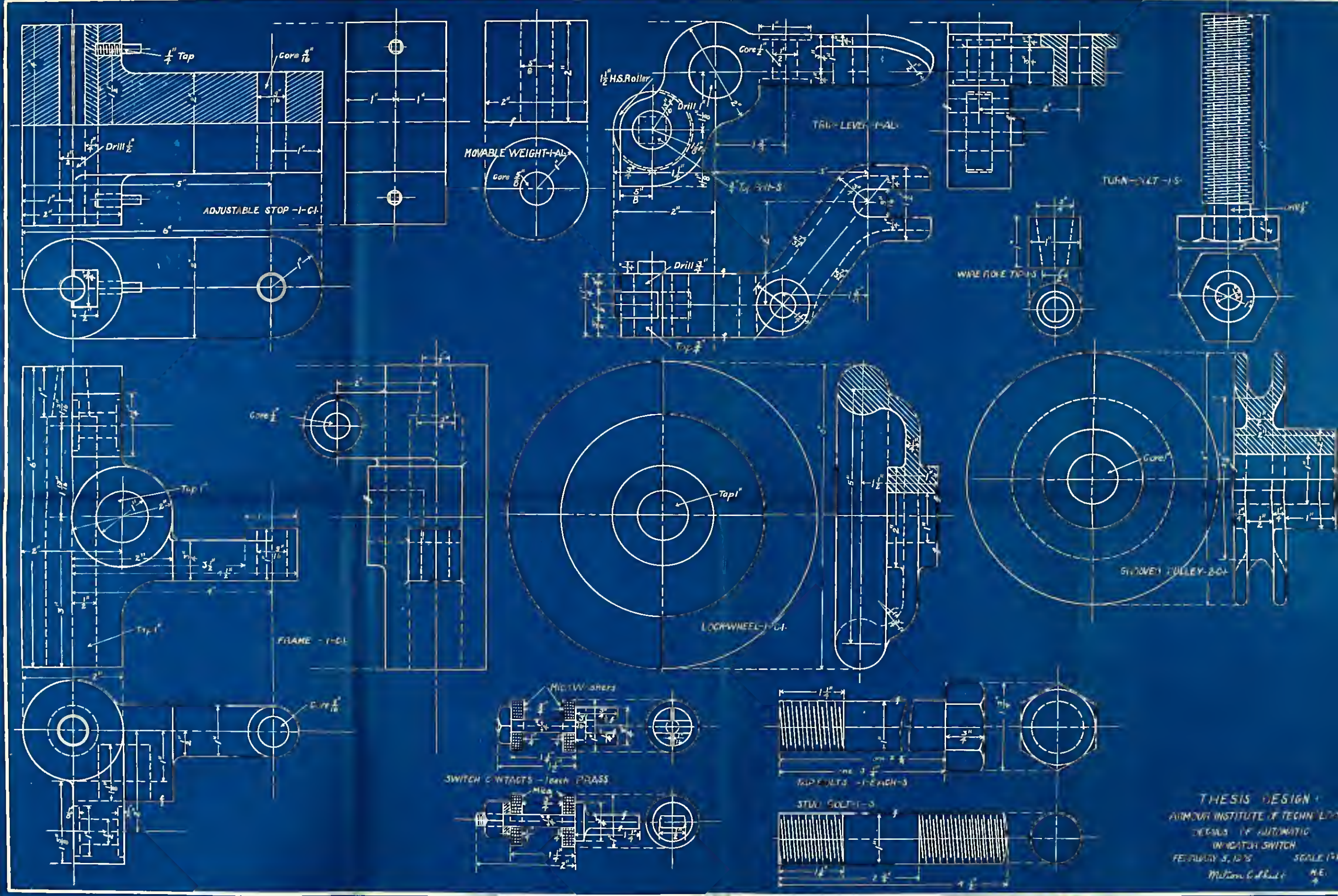

THESIS DESIGN
ARMOUR INSTITUTE OF TECHN
DETAILS OF AUTOMATIC
INDICATOR SWITCH
FEBRUARY 3, 1915 SCALE 1
Milton C. [illegible] M.E.

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